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Designing Chebyshev Filters for Practical Operation

Part 1

Various processes exist for LC filter calculations. But since the complete calculation process for Chebyshev filters is very detailed, people like to use so-called filter catalogues. The use of data from such a filter catalogue is explained here, with the help of examples.

1. GENERAL

The filter catalogue I have, the book from Pfitzenmeier [1], contains the data for deep-passes, in standardised form, for all possible graph curves, from the simplest right up to very extensive patterns. As a result, the book is over 500 pages thick, and is really impenetrable for someone not used to using such sources. So now we have to learn how to handle the data from this book.

Through a relatively simple adaptation of the computing method, high-passes, band passes and band elimination filters can also be dimensioned using the same tables.

Using them can be made considerably easier by means of three simplifications clarified below.

Various filters are then examined, once the material has been made rather more accessible, so that anyone should be in a position to lay out filters of this kind for his or her own applications.

2. THE SIMPLIFICATIONS

Basically, there are two different types of filter: symmetrical and asymmetrical.

Symmetrical filters have the same impedance at the input and output (e.g. 50Ω), whereas the asymmetrical formats transform to a greater or smaller degree - i.e., the input and output impedances are different.

Modern equipment design involves a series of stages which all have the same

input and output impedances (e.g. 50Ω). But this applies only to filter circuits which also have the same input and output impedances. For this reason, we shall not go any further into asymmetrical types of filter here. Transformation circuits are a different area. So that already halves the amount of data in question.

The data listed in Pfitzenmeier [1] go right up to fifteenth-grade filters - i.e. those containing a total of 15 structural elements. But firstly, the filter curves which they can produce are hardly ever needed in practical amateur applications, and secondly, they are far too complex to adjust without expensive measuring equipment.

Let us therefore restrict the complexity of filters for practical use to the seventh degree.

The book of tables referred to comprises filter data for transmission curves with a ripple of from (about) 1.25dB, with a reflection factor of 50%, right up to a ripple of 0.000004dB and 0.1% reflection factor. Whilst the one extreme is probably too "coarse-grained" for most applications, the other extreme brings no additional advantages with regard to steeper curves in comparison to a layout without ripple (Butterworth curve).

Thus, for practical purposes, only a certain part of the information available will be required, and so here we are restricting discussion to filters with a ripple of approximately 0.1dB, 0.2dB and 0.5dB, and to Butterworth filters. Thus the entire book can be simplified down to a few easily accessible tables. Since the ripple tends to be rather greater in practice, due to unavoidable slight tolerances, we always go to the next lowest table when taking the available data from the book of tables. For the applications here, that means 0.0875dB, 0.1674dB and 0.4576dB. Since the tables are laid out for smooth return loss values, correspondingly skewed numbers are obtained for the individual ripple values. For the ripple values referred to above, the associated return loss values are 17dB, 14dB and 10dB, and the reflection factors are 14.12%, 19.95% and 31.62%. For the sake of completeness, the coefficients are also given for the Butterworth cycle - i.e. for filters with a flat-line graph in the transmission range.

3. PRINCIPLES

In contrast to filters with as constant an attenuation course as possible over the entire transmission range, Chebyshev filters allow a certain ripple in the transmission range (usually relatively slight). As a result, the transition into the attenuation range becomes steeper.

Thus in a deep-pass, above the limiting frequency a required minimum attenuation is obtained more rapidly than if the equipment is designed to give the maximum flat transmission range. Another consequence of this is that a simpler circuit with fewer structural elements can already attain the required attenuation value. Fig.1 should make the difference clearer. It shows the curves for a seventh-grade filter, with a Butterworth gradient, and a filter with a Chebyshev gradient with 0.5dB ripple.

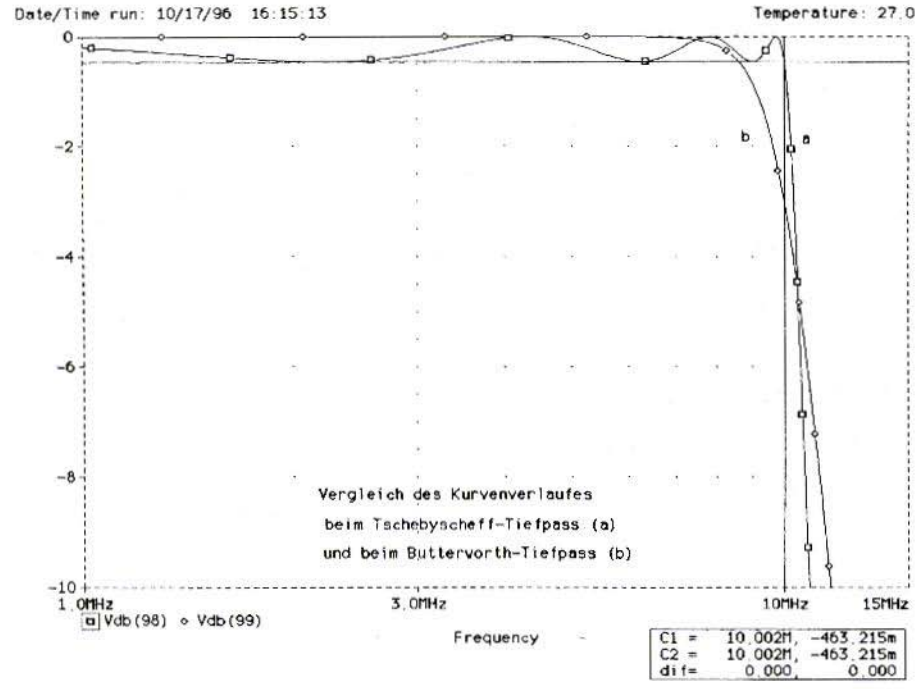


Fig. 1: Gradients of two Seventh-Grade Filters: a) Chebyshev Deep Pass b) Butterworth Deep Pass

***Vergleich des Kurvenverlaufes beim Tschebyscheff-Tiefpass (a) und beim Butterworth-Tiefpass (b)* =Comparison of gradient in Chebyshev deep pass and Butterworth deep pass**

All these data refer only to deep-pass equipment. The high-pass filters will be considered a little later on.

It will be noted that the Butterworth gradient is completely flat in the transmission range, but that an increase in the attenuation becomes apparent quite some way before the limiting frequency is reached (- 3dB at 10 MHz!). The Chebychev filter certainly also displays a certain attenuation at individual points (app. 0.5dB), but in contrast continues to maintain this value right up to the limiting frequency, and then the attenuation grows steeper. The two curves intersect at an attenuation level of about 4.8dB. From this point onwards, the Chebychev filter displays a higher attenuation level as the frequency rises. (The two cursors in the PSPICE simulation were both set to the limiting frequency of 10,000 MHz.)

To provide greater help for the practical users, rather than for theorists, these filters were not standardised to 1 Hz as usual, but were laid out for an application which was practically possible - namely, with a limiting frequency of 10 MHz. From this basis, conversions can be made to other limiting frequencies, using the standard units for the structural elements.

Return Loss 10dB (Riple app. 0.5dB)

Degrees Coefficients

	a1	a2	a3	a4	a5	a6	a7
3	1,552904	1,105808	1,552904	-	-	-	-
5	1,662454	1,243589	2,495603	1,243589	1,662454	-	-
7	1,694043	1,273338	2,593997	1,362738	2,593997	1,273338	1,694043

Return Loss 14dB (Riple app. 0.2dB)

Degrees Coefficients

	a1	a2	a3	a4	a5	a6	a7
3	1,187978	1,154234	1,187978	-	-	-	-
5	1,300426	1,345877	2,127107	1,345877	1,300426	-	-
7	1,333498	1,388901	2,238741	1,515988	2,238741	1,388901	1,333498

Return Loss 17dB (Riple app. 0.1dB)

Degrees Coefficients

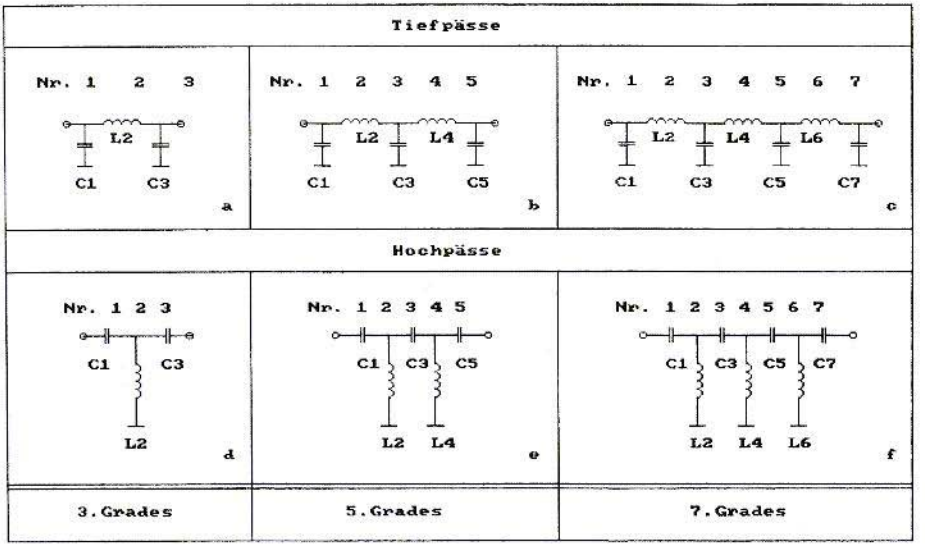
	a1	a2	a3	a4	a5	a6	a7
3	0,999435	1,142764	0,999435	-	-	-	-
5	1,115397	1,373987	1,944023	1,373987	1,115397	-	-
7	1,150092	1,427636	2,068219	1,583769	2,068219	1,427636	1,150092

Butterworth Gradient (Riple 0dB)

Degrees Coefficients

	a1	a2	a3	a4	a5	a6	a7
3	1,000000	2,000000	1,000000	-	-	-	-
5	0,618033	1,618033	2,000000	1,618033	0,618033	-	-
7	0,445041	1,246979	1,801937	2,000000	1,801937	1,246979	0,445041

Table 1: Standardised Component Coefficients



Figs.2a-2f: Wiring Diagrams for Low-Coil Deep-Pass and High-Pass Third-Grade to Seventh-Grade Filters (Notice the Component Numbering!)
***Tiefpässe* = Deep passes, *Hochpässe* = High passes, *Grades* = Stages**

It should be pointed out once again that a rise in attenuation to 3dB is usually defined as the limiting frequency for Butterworth filters, whereas the limiting frequency for the Chebychev filters is defined as the point at which the permitted ripple value is exceeded!

4. CALCULATION PROCEDURE

Table 1 shows the selected original values from [1]. They allow us to determine the components for a corresponding Chebychev deep pass.

First we need two simple calculations - namely, the one for "reference inductance" and the one for "reference capacitance". We use the following formulae:

$$L_b = \frac{R_b}{2 \cdot \pi \cdot f_b} \qquad C_b = \frac{1}{R_b \cdot 2 \cdot \pi \cdot f_b} \qquad (1)$$

Here, the impedance (Rb) is given in Ohms and the limiting frequency (fb) in Hertz, the inductance being in Henrys and the capacitance in Farads. These then have to be converted into more practical values, such as microHenrys and picoFarads. If we also fix an operating impedance of 50Ω, we arrive at these simple formulae:

$$Lb = 7.95775 / fb \qquad (2)$$

with Lb in µH, fb in MHz and Z = 50Ω

$$Cb = 3183.1 / fb$$

with Cb in pF, fb in MHz and Z = 50Ω

Starting from these two values, we can now calculate the components for the circuit. The wiring diagrams in Fig's.2a to 2f can be used for this.

Three important things can be seen straight away:

a) Chebychev deep-passes are made up only of series inductances and shunt capacitances. The Pi-network is generally preferred, as it needs fewer coils.

b) Chebychev deep passes are made up only of series capacitances and shunt inductances. The T-network is generally preferred, as it needs fewer coils.

c) The components are numbered from 1 through to n, these numbers already being identical with the numbers of the associated filter coefficients of Table 1! This is true irrespective of whether we are dealing with a deep-pass or a high-pass filter!

4.1. Calculation Process for a Deep-Pass Filter

For a deep-pass filter, the reference values - reference inductance and reference capacitance - are to be multiplied by the associated coefficients.

In the low-coil Pi-network, component 1 is a capacitance. Its value can be defined as the reference capacitance, multiplied by coefficient a1. Likewise, for component 2 we multiply with coefficient a2, and so on.

Deep-pass: component n = reference value . an

4.2. Calculation Process for a High-Pass Filter

For a high-pass filter, the reference values (reference inductance and reference capacitance) are to be divided by the associated coefficients. For the low-coil T-network, component 1 is also a capacitance. Its value can be defined as the reference capacitance divided by the coefficient a1. Likewise, for component 2 we divide by coefficient a2. High-pass: component n = reference value / a_n

4.3. Calculation for Band-Passes and Band-Elimination Filters

In a similar process to that used to calculate deep-pass and high-pass filters, band-pass and band-elimination equipment can be calculated by conversion from the deep-pass components. Since in the practical application involved these are of less significance, we shall not attempt to clarify them here. These applications are explained in sufficient detail in the literature source referred to, so additional information can be obtained there if required.

5. LITERATURE

[1] G.Pfitzenmeier:
Deep-Pass Book of Tables
(1971)Siemens Fachbücher,
Siemens AG

[2] D.Eckart Schmitzer, DJ4BG:
Danger - Parasites!
VHF Communications 2/1997,
pp. 97-102

D.Eckart Schmitzer, DJ4BG

Designing Chebyshev Filters for Practical Operation

Part-2

6. SPECIMEN CALCULATIONS

6.1. Specimen Calculation for a Low-Pass Filter

We can now calculate the components of a filter, based on the clarifications in the previous chapters. As an example, let us design a fifth-grade low-pass filter, with a limiting frequency of 10 MHz and an impedance of 50Ω, which is to have around 0.2dB ripple.

The reference values for the inductance and capacity can be obtained using formula (2) above (similarly converted to the more practical values H and pF):

$L_b = 7.95775 / f_b = 7.95775 / 10\ (MHz)$
$= 0.795775\ \mu H$

$C_b = 3183.1 / f_b = 3183.1 / 10\ (MHz)$
$= 318.310\ pF$

If we now multiply these reference values by the coefficients from the table (here, for example, for 0.2dB ripple), we immediately obtain the component values sought. The values used in the example are underlined in Table 1.

The calculation process is shown again below in diagrammatic form:

a. Calculate reference values L_b and C_b from impedance and desired limiting frequency.

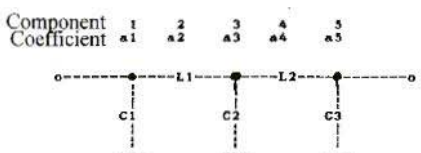
b. Multiply reference values by coefficients from table:

Component 1 = Reference value (here C_b) . coefficient 1

Component 2 = Reference value (here L_b) . coefficient 2, etc.

Coefficients from table for 0.2dB ripple:

a1 = 1.300426, a2 = 1.345877
a3 = 2.127107, a4 = 1.345877
a5 = 1.300426



C1 = C_b · a1 = 318,310 pF · 1,300426 =
= 413,9386 ≈ 414 pF

L1 = L_b · a2 = 0,795775 µH · 1,345877 =
= 1,071015 ≈ 1,071 µH

C2 = C_b · a3 = 318,310 pF · 2,127107 =
= 677,0794 ≈ 677 pF

L2 = L_b · a4 = 0,795775 µH · 1,345877 =
= wie L1

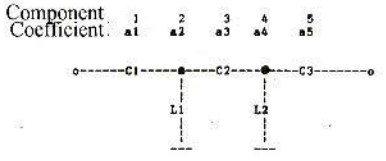
C3 = C_b · a5 = 318,310 pF · 1,300426 =
= wie C1

In all cases it is recommended that component values and coefficients should be entered into the calculation as precisely as possible, and that the component values should not be rounded off until the end of the calculation. It will usually not be possible to avoid some calibration work to achieve the right inductance values, while the capacitances must be made as close as possible to the rated value by wiring up standard values in parallel: for example, by combining 390 and 24pF to give 414pF.

Parasitic elements, such as the self-capacitances of the coils and the external inductance of the capacitors, have not been taken into consideration yet! These were discussed in greater detail in [2].

6.2. Specimen Calculation for a High-Pass Filter

A fifth-grade high-pass should be laid out with the same basic data as the low-pass referred to above. So it should have a limiting frequency of 10 MHz and an impedance of 50Ω, together with app. 0.2dB ripple. The reference values determined are the same as those in Section 6.1., which gives us:



C1 = C_b · a1 = 318,310 pF : 1,300426 =
= 244,7736 ≈ 244,8 pF

L1 = L_b · a2 = 0,795775 µH : 1,345877 =
= 0,591269 ≈ 0,591 µH

C2 = C_b · a3 = 318,310 pF : 2,127107 =
= 149,6445 ≈ 149,6 pF

L2 = L_b · a4 = 0,795775 µH : 1,345877 =
= wie L1

C3 = C_b · a5 = 318,310 pF : 1,300426 =
= wie C1

6.3. Simulation Results for Above Specimens

The rounded-off component values for the two examples were entered into PSPICE as a node list, and displayed over a range of from 1 to 100 MHz.

For the low-pass, Fig.3, curve a gives the result for the attenuation range up to 100dB, in order to show the long-range attenuation. Fig.4, curve a gives the attenuation up to 3dB, to demonstrate the ripple in the transmission band. In Fig.3, both cursors are exactly on the limiting frequency of 10.0 MHz, while in Fig.4 cursor 1 is on the limiting frequency and cursor 2 is at the left-hand edge of the diagram, i.e. on 1 MHz.

In Fig's. 3 and 4, the "b" curves show the results for the high-pass. It can easily be seen from these diagrams that the low-pass and the high-pass produce gradients which are exactly symmetrical

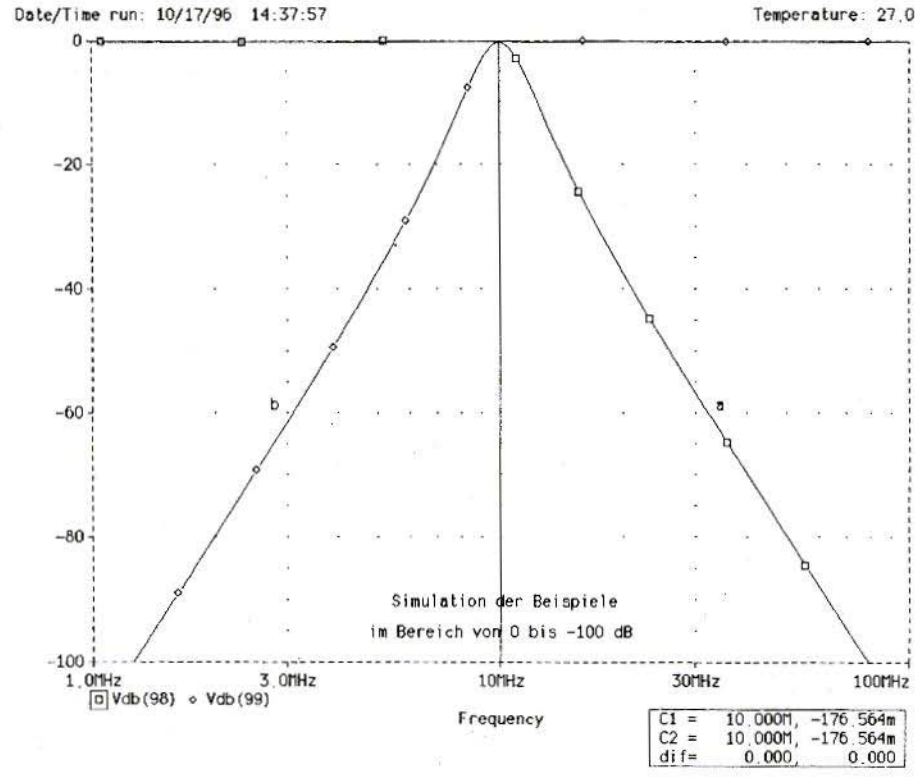


Fig.3: Simulation of Specimens in Range between 0 and -100dB

to the selected limiting frequency. It is also clear that, as stated initially, the ripple values are rounded off. What we are actually seeing here in the display field is a simulation of the basic ripple value of about 0.176dB (cursor C1 = 10,000 M, - 176.564 m., i.e. 176,564 milli-dB)!

It should be pointed out once again here that in Chebyshev filters the limiting frequency is not the 3dB point (!) but the point of the curve at which the attenuation exceeds the maximum desired ripple value. So for a filter with 0.2dB ripple, the limiting frequency is the point after which the attenuation just exceeds the value of 0.2dB!

7. FILTER TABLES

In Part 1, filter types with varying ripple values were selected. The components for these filters, and those for the specimens in Section 6, were calculated for a limiting frequency of 10 MHz and for 50Ω, and were listed in tables. So the values for these types of filter can be converted by means of simple scaling up or down (see Section 8) for any limiting frequency or impedance required.

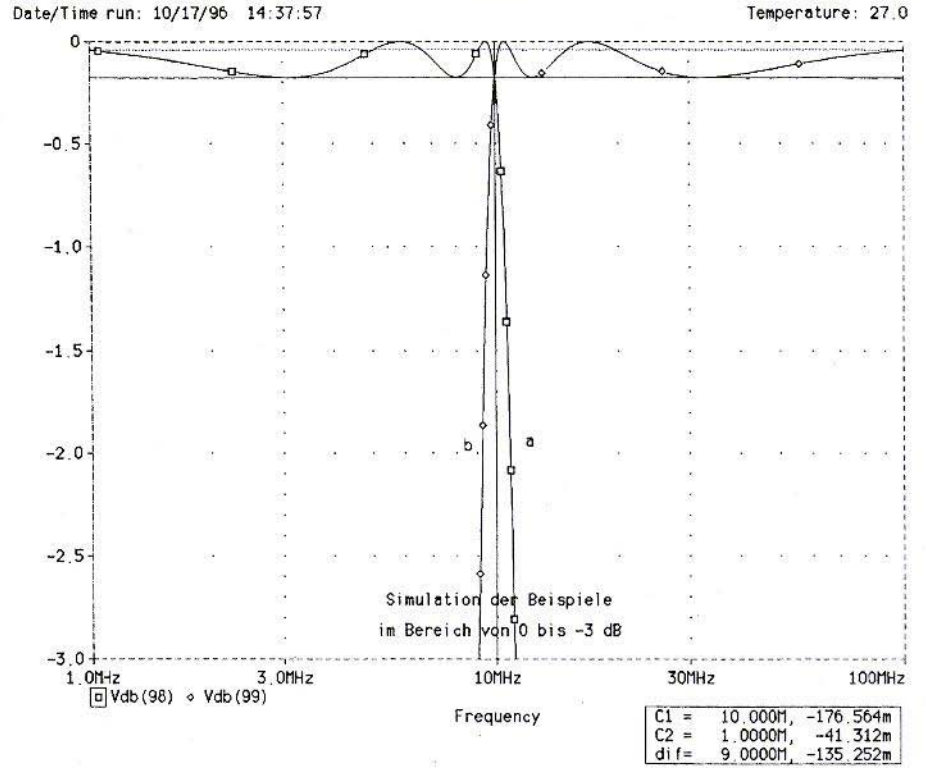


Fig.3: Simulation of Specimens in Range between 0 and -3dB

7.1. Low-Passes

The components are equally suitable for an impedance of 50Ω with a limiting frequency of 10.0 MHz.

The reference values involved have already been calculated in Section 6.1. with:

L_b = 0.795775 µH and C_b = 318.310 pF

A delta circuit is used (not so many coils). Thus we obtain the component values in pF and H shown in Table 3.

The numbering differs from the usual sequence in that the component numbers coincide with the coefficients, as can also be seen from the circuit diagrams in Fig's.2a to 2c in Part 1.

The values calculated were precise, and were not rounded up or down until later to give practical values (with sufficient accuracy).

7.2. High-Passes

The components are also suitable for an impedance of 50Ω with a limiting frequency of 10.0 MHz. The reference values calculated in Section 6.1. also apply here, with:

L_b = 0.795775 µH and C_b = 318.310 pF.

A star circuit is used here (not so many coils). Thus we obtain the component

Echodämpfung 10 dB (Welligkeit rund 0,5 dB)

Grad: Bauteilewerte in pF und µH:

	C1	L2	C3	L4	C5	L6	C7
3	494,3	0,8800	494,3	-	-	-	-
5	529,2	0,9894	794,4	0,9894	529,2	-	-
7	539,2	1,0133	825,7	1,0844	825,7	1,0133	539,2

Echodämpfung 14 dB (Welligkeit rund 0,2 dB)

Grad: Bauteilewerte in pF und µH:

	C1	L2	C3	L4	C5	L6	C7
3	378,1	0,9185	378,1	-	-	-	-
5	413,9	1,0710	677,1	1,0710	413,9	-	-
7	424,5	1,1053	712,6	1,2064	712,6	1,1053	424,5

Echodämpfung 17 dB (Welligkeit rund 0,1 dB)

Grad: Bauteilewerte in pF und µH:

	C1	L2	C3	L4	C5	L6	C7
3	316,5	0,9094	316,5	-	-	-	-
5	355,0	1,0934	618,8	1,0934	355,0	-	-
7	366,1	1,1361	658,3	1,2603	658,3	1,1361	366,1

Butterworth-Verlauf (Welligkeit 0 dB)

Grad: Bauteilewerte in pF und µH:

	C1	L2	C3	L4	C5	L6	C7
3	318,3	1,5915	318,3	-	-	-	-
5	196,7	1,2876	636,6	1,2876	196,7	-	-
7	141,7	1,0082	573,6	1,5916	537,6	1,0082	141,7

Table 3: Component Values for Low-Passes at 10.0 MHz and 50Ω
***Echodämpfung* = Reflection loss, *Welligkeit* = Ripple, *Rund* = Approximately, *Grad* = Degree, *Bauteilwerte* = Component values, *Und* = And, *Butterworth-Verlauf* = Butterworth gradient**

Echodämpfung 10 dB (Welligkeit rund 0,5 dB)

Grad: Bauteilewerte in pF und µH:

	C1	L2	C3	L4	C5	L6	C7
3	205,0	0,7196	205,0	-	-	-	-
5	191,5	0,6399	127,5	0,6399	191,5	-	-
7	187,9	0,6250	122,7	0,5841	122,7	0,6250	187,9

Echodämpfung 14 dB (Welligkeit rund 0,2 dB)

Grad: Bauteilewerte in pF und µH:

	C1	L2	C3	L4	C5	L6	C7
3	267,9	0,6894	267,9	-	-	-	-
5	244,8	0,5913	149,6	0,5913	244,8	-	-
7	238,7	0,5730	142,2	0,5249	142,2	0,5730	238,7

Echodämpfung 17 dB (Welligkeit rund 0,1 dB)

Grad Bauteilewerte in pF und µH:

	C1	L2	C3	L4	C5	L6	C7
3	318,5	0,6964	318,5	-	-	-	-
5	285,4	0,5792	163,7	0,5792	285,4	-	-
7	276,8	0,5574	153,9	0,5025	153,9	0,5574	276,8

Butterworth-Verlauf (Welligkeit 0 dB)

Grad Bauteilewerte in pF und µH:

	C1	L2	C3	L4	C5	L6	C7
3	318,3	0,3979	318,3	-	-	-	-
5	515,0	0,4918	159,2	0,4918	515,0	-	-
7	715,2	0,6281	176,7	0,3979	176,7	0,6281	715,2

Table 4: Component Values for High-Passes at 10.0 MHz and 50Ω
***Echodämpfung* = Reflection loss, *Welligkeit* = Ripple, *Rund* = Approximately, *Grad* = Degree, *Bauteilwerte* = Component values, *Und* = And, *Butterworth-Verlauf* = Butterworth gradient**

values in pF and H listed in Table 4. The numbering differs from the usual sequence in that the component numbers coincide with the coefficients, as can also be seen from the circuit diagrams in Fig's.2d to 2f in Part-1.

The values calculated were precise, and were not rounded up or down until later to give practical values (with sufficient accuracy).

8. SCALING UP OR DOWN

8.1. Conversion to Another Limiting Frequency

In order to convert the filters above for use with other limiting frequencies, the capacities and inductances merely need to be multiplied by the ratio of the frequencies:

$$C'' = C' \cdot (f_1 / f_2)$$

$$L'' = L' \cdot (f_1 / f_2)$$

where f_1 for our limiting frequency of 10 MHz, used in the tables, is:

$$C'' = C' \cdot (10\ \text{MHz} / f_2)$$

$$L'' = L' \cdot (10\ \text{MHz} / f_2)$$

Example:

The dimensions of a filter are to be changed to give it a limiting frequency of 14.5 MHz. This gives us:

$$C'' = C' \cdot (10\ \text{MHz} / 14.5\ \text{MHz})$$

$$L'' = L' \cdot (10\ \text{MHz} / 14.5\ \text{MHz})$$

i.e.

$C'' = C' \cdot 0.68966$

and

$L'' = L' \cdot 0.68966$

where C' and L' are the original values for a capacity or inductance at 10 MHz and C" and L" are the desired values for the new frequency.

Check: Higher frequencies, smaller capacities and inductances; lower frequencies, bigger capacities and inductances!

8.2. Conversion to Another Impedance

To convert to another impedance, the capacities are multiplied by the ratio of the impedances (Z1/Z2), while the inductances are divided by the same ratio, i.e.

$$C'' = C' \cdot (Z_1 / Z_2)$$

$$L'' = L' / (Z_1 / Z_2)$$

Starting from the impedance of 50Ω for Z1 selected here, this gives:

$$C'' = C' \cdot (50 / Z_2)$$

$$L'' = L' / (50 / Z_2)$$

Example:

A filter is to be converted to an impedance of 75Ω. This gives us:

$$C'' = C' \cdot (50 / 75)$$

$$L'' = L' / (50 / 75)$$

i.e.

$C'' = C' \cdot 0.6666$ and

$L'' = L' / 0.6666$

where C' and L' are the original values at 50Ω and C" and L" are the desired values at the new impedance.

Check: Higher impedance, smaller capacities and bigger inductances; lower impedance, bigger capacities and smaller inductances!

9. CHECK

All the component values shown in the above tables were entered into PSPICE and the curves obtained were checked. But it must be pointed out once again that parisitic elements are not taken into account here see [2]. Thus in practise it will be necessary to use slightly lower component values to obtain the precise limiting frequencies desired.

The follow-up article by D.Eckart Schmitzer, DJ4BG on this subject will be appearing in a futures issue of VHF Communications:

LC Filters with Attenuation Peaks Based on Chebyshev Filters

Editor

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